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The Wind Dissemination of the Spores of Bunt or Stinking Smut of Wheat

By

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THE WIND DISSEMINATION OF THE SPORES OF BUNT OR STINKING SMUT OF WHEAT

By F. D. Heald and D. C. George*

INTRODUCTION

During recent years the increased prevalence of stinking smut in the wheat fields of the Indand Empire has furnished one of the most important agricultural problems. This disease has been a growing menace to wheat production, notwithstanding the fact that seed disinfection has been very generally practiced. No satisfactory explanation had ever been offered for this rather unique condition previous to the investigations upon which this report is based. The recognition and establishment of the cause of the wide-spread occurrence of stinking smut is fundamental to the development of rational and effective methods of control.

The wide-spread occurrence of a fungous disease points to an effective dissemination, either natural or artificial. Fungous troubles may be seed-borne, or they may be disseminated by wind, water, insects, birds or other animals or by the commercial or agricultural practices of man. Since early times the stinking smut of wheat has been recognized as one of the most important seed-borne diseases, and seed treatment with fungicides has generally been effective in its control. The failure to secure the desired relief by seed treatment naturally suggests some other general method of dissemination aside from the use of infected seed. Work was begun on this phase of the smut problem in the summer of 1915 and has been continued up to the present time. Before presenting this work, a brief statement will be made concerning the general methods of dissemination of the smut fungi of cereals and the time when infection takes place.

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THE DISSEMINATION OF SMUT FUNGI OF CEREALS

The various smut fungi of cereals show a pronounced diversity in the methods of spore dissemination and in the time when infection takes place. Three general types may be recognized and a brief discussion of these will be presented in order that a clear view may be obtained of the particular species which forms the subject of this study. According to time of infection, the three groups are as follows:

1. Species producing a blossom infection.
2. Species infecting growing plants or those approaching maturity.
3. Species infecting only young seedlings.

In the first group the smut spores reach maturity in infected heads at a time when the flowers of the normal heads are in the blossom stage. The loose powdery mass of smut spores is dissipated by the wind, and the spores carried to the projecting feathery stigmas of the healthy plants. There is a direct germination of the spores with the infection of the young developing ovaries. This intraseminal infection causes no outward indication of the presence of an internal mycelium and the infected grains assume normal form and size. Such infected grains, when planted, may produce diseased progeny. The spread of the disease is due, first, to wind-borne spores during the blossoming period, and second, to the use of infected seed. This behavior is well illustrated by the loose smut of wheat (*Ustilago tritici*) and the naked smut of barley (*Ustilago nuda.*)

The second type is illustrated by the common smut of corn. Young plants or those approaching maturity are infected by wind-borne secondary spores or sporidia, which have resulted from the germination of the smut spores in the surface layers of the soil. The infections in this case are localized and not systemic, the mycelium penetrating the host only in the tissues adjacent to the tumors. Although spores of this species may be spread in other ways, the wind is the principal agent in the work of dissemination.

In the third type, which includes the larger number of our cereal smuts, the infection can take place only during the young or seedling stage of the host. The first essential for infection is the presence of smut spores in close proximity to the germinating seeds. These spores may be lodged upon the seeds and carried with them into the soil, or they may already be in the soil at the time of seeding. The source of the spores in the latter case must be either from a previous smutty crop on the ground (residual) or from adjacent or distant infected fields (wind-borne). Notable illustrations of this third type are loose smut of oats (*Ustilago avenae*) covered smut of barley (*Ustilago hordei*) and bunt or stinking smut of wheat (*Tilletia tritici* and *Tilletia foetans*). In the latter species all of the above sources of infection may occur, but our investigations have shown that wind-borne spores are very prevalent in Eastern Washington and adjacent territory. This is a phase of the dissemination of bunt which will receive special consideration in the following pages.

STUDIES OF STINKING SMUT IN WASHINGTON

A study of the work published by the Washington Experiment Station shows that first attention was given to seed treatment the same as in other wheat regions of the world. By 1911 the increased prevalence of smut in the Inland Empire due to fall seeding suggested the possibility of soil infection and the part of wind-disseminated spores in this increase was first suggested by Richardson in a thesis written in 1911 and further elaborated by Heald and Woolman in 1915 and 1916. The following publications by the Washington Station are given in chronological order and the brief summaries show the changing conditions and the development of our knowledge on the life history, prevalence, and control of bunt:

Piper, Chas. V.

1893. Common fungous diseases and methods of prevention. Bul. Wash. Agr. Exp. Sta. 8:131-144. 1894.
Description of stinking smut incorrectly referred to as *Tilletia foetans* Berk. & Curt.; recommends copper sulphate and hot water treatment, p. 135-136.

Beattie, R. Kent.

1902. The formalin treatment for wheat and oat smut. Bul. Wash. Agr. Exp. Sta. 54:1-8.
Considers loss, variation in susceptibility of varieties, description of smut, copper sulphate and hot water treatments.

Beattie, R. Kent.

1902. (?) The formalin treatment for wheat smut. Press Bulletin Wash. Agr. Exp. Sta. (unnumbered) 4 pages.
Considers nature of smut, losses, ineffectiveness of bluestone treatment, and recommends the formalin treatment.

Lawrence, W. H.

1907. Some important plant diseases of Washington. Bul. Wash. Agr. Exp. Sta. 83:1-56. 1907.
Stinking smut (*Tilletia tritici*) described and the formaldehyde treatment recommended, p. 43-45.

Humphrey, H. B.

? The preventing of the stinking smut of wheat. Press Bulletin (unnumbered) Wash. Agr. Exp. Sta.

Anonymous.

1911. The anti-smut campaign. Press Bulletin Wash. Agr. Exp. Sta. No. 1.
Notes loss, increased prevalence due to fall seeding, possibility of soil infection and recommends copper sulphate or formaldehyde treatment.

Richardson, A. M.

1911. A comparative study of the methods of control of the stinking smut of wheat. Thesis (unpublished) on file in Library, State College of Washington.
Historical statement, life history of the fungus, partially smutted kernels, wind dissemination, treatments: hot water, copper sulphate and formaldehyde, are the prinicpal topics discussed. Ineffectiveness of the two methods generally employed, blue stone and formaldehyde, reported by practical farmers. Tests of formaldehyde or copper sulphate and the two combined.

Humphrey, H. B.

1912. The preventing of the stinking smut of wheat. Popular Bul. Wash. Agr. Exp. Sta. 48:1-3.
Considers copper sulphate and formalin treatment, and points to soil infection as explanation of certain cases of ineffective results; also records failure of fungicides to penetrate smut balls.

Anonymous.

1912. Treating seed wheat for smut. Newspaper Bulletin Wash. Agr. Exp. Sta. No. 51.
Recommends either the formalin or bluestone seed treatment; emphasizes the importance of removing unbroken smut balls from the seed grain.

Woolman, H. M.

1914. Stinking smut of wheat. Popular Bul. Wash. Agr. Exp. Sta. 73, 8 pages.
Considers life history, breeding for resistant varieties, differences in susceptibility of varieties, time of application and strength of copper sulphate or formaldehyde in seed treatment, effect of threshing injury on germination of treated grain, persistence of spores in soil and effect of time of planting on the amount of smut.

Anonymous.

1914. Smut. Press Bulletin Wash. Agr. Exp. Sta. No. 113.
Refers only to Popular Buleltin 73.

Cardiff, I. D., et al.

1914. Report on fires occurring in threshing separators in East Washington during the summer of 1914. Bul. Wash. Agr. Exp. Sta. 117:1-22.
Demonstrates that smut dust is one of the causes of explosions in threshing separators and recommends methods of prevention and control.

Anonymous.

1915. Bunt or stinking smut of wheat. Newspaper Bulletin Wash. Agr. Exp. Sta. No. 160.
A summary of results reported later in Bulletin 126.

Heald, F. D., and Woolman, H. M.

1915. Bunt or stinking smut of wheat. Bul. Wash. Agr. Exp. Sta. 126:1-24.
Considers life history of smut fungus, effect on the host, infection from smutty seed, infection from spores in the soil, residual or wind borne, control by crop rotation, clean seed, treatment with fungicides, cultural practices and breeding and selection of varieties.

Heald, F. D.

1916. Some new facts concerning wheat smut. Proc. Wash. State Grain Growers, Shippers and Millers Association, 1916:38-45.
Emphasizes the occurrence of partially smutted grains and gives further evidence of a general and extensive wind dissemination of the spores.

Woolman, H. M.

1916. The prevention of wheat smut. Proc. Wash. State Grain Browers, Shippers and Millers Association, 1916:45-49.
Emphasizes the importance of using clean seed and using one of the standard seed treatments; gives methods of combatting soil infection from previous crops or from wind-blown spores.

Anonymous.

1916. Smut. Newspaper Bulletin Wash. Agr. Exp. Sta. No. 191. Emphasizes the soil infection by wind-blown spores and recommends either seeding before threshing time or late seeding or the abandonment of summer fallow wherever possible.

POSSIBILITIES OF WIND DISSEMINATION OF STINKING SMUT

The possibilities of a wind dissemination of bunt or stinking smut have been mentioned by a number of investigators. The first to be considered is the possibility of the production of wind-borne sporidia or secondary spores. This is not an unknown method of dissemination in cereal smuts, as may be noted from the following quotation from Brefeld:* "Some of these bud conidia are able to continue their budding in the air also and to form conidia there, which are disseminated through the air; as, for example, the bud conidia of the maise smut."

It has been observed that when spores of stinking smut are abundant in a soil, they may produce promycelia which come to the top of the moist soil and produce fascicles of sporidia in such profusion as to cause a grayish growth visible to the naked eye. This is apparently the condition which Brefeld had in mind when he mentioned the possibility of diffusible air conidia in bunt, or Tilletia species. If such conidia are borne away by wind or air currents, we have no evidence at present that they play a part in the general spread of stinking smut. Von Tubeuf,‡ who has experimented extensively with bunt in Europe, states that there is no spread of this disease from one plat to another and therefore concludes that there is no dissemination by aerial conidia.

There is little possibility of any wind dissemination of spores directly from the smutted heads as occurs in the case of loose

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*Brefeld, O. Investigations in the general field of mycology. Part XIII, p. 7. English translation by Frances Dorance.

‡Von Tubeuf, K. F. Arb. aus der Biol. Abteilung f. Land- u. Forstwirtschaft am Kaiserlichen Gesundheitsamt, 2:179-349. 1901.

smut. The smutted berries are wholly or partially concealed by the glumes and the smut mass covered by an enclosing membrane. Occasionally there may be a mechanical rupture of the enclosing mebmrane or the depredations of insects may result in the exposure of the smut spores, but there is no evidence that the agitation of these heads by the wind causes any appreciable liberation of the spores. Previous to harvest time there has been little or no opportunity for the dissemination of the smut spores. The first real opportunity offered for the setting free of the smut spores is in the threshing operations. It has long been a matter of general observation that many of the smut berries are broken in threshing and the spores dissipated. The extent to which this occurs depends on numerous factors, such as variety, maturity of crop at harvest, climatic conditions and speed of the threshing machine. The yield from very smutty fields sometimes shows a relatively small number of unbroken smut berries, the greater number having been broken. Part of the spores from the broken smut kernels adhere to the surfaces of sound grains, or are lodged in the sutures and brushes, but many must be carried out through the straw carrier, or stacker. The ultimate fate of the latter is of the utmost importance and indicates the possibility of wide-spread dissemination of these spores by the wind.

SUGGESTIVE EVIDENCE OF THE WIND DISSEMINATION OF SMUT

Various observations and experiences have given strong suggestive evidence of the wind dissemination of the spores of bunt. The following are the principal suggestive features that were brought to our attention and led up to the work which established the wide-spread prevalence of wind-disseminated spores.

1. The visible clouds of smut dust which issue from the threshing machines whenever the run is from a smutty field. Even with the use of ordinary separators, the innumerable number of settings must certainly set free into the air countless billions of spores, while the use of the combine serves as

an even more effective distributor. It must at once be evident that the spores in these visible clouds, being very minute, do not settle to the ground at once, and that their final place of deposit depends largely on the velocity of the wind. Any reflection on this matter would certainly lead to the conclusion that many of the smut spores set free from each threshing operation might be carried away for miles and thus scattered over the fields.

2. The presence of smut spores on vegetation distant from any threshing operation. This was first brought to our attention when making microscopic examinations of scab lesions on the leaves of apple trees from the College orchard. Wind dissemination of the spores was the evident explanation for their presence in such a location and this accidental discovery led to the systematic examination of foliage from various localities as will be discussed later.

3. Smutty wheat from clean seed on new land. This has been referred to in a previous publication* and will not be repeated in full. In some 1914 plantings on new soil using hand-threshed grain from smut-free heads, the percentages of smutted plants varied from a fraction of one per cent to sixty per cent. No other possible explanation for these results could be found except that the ground had been seeded with wind-blown spores.

4. The ineffectiveness of ordinary seed treatment for fall seeding. Two explanations for the failure to secure satisfactory results by seed disinfection had been given: first, the failure to remove the unbroken smut balls, either before or during the process of the treatment; second, soil infection due to a previous smutty crop on the same land. When, however, both of these possibilities were eliminated, carefully treated wheat frequently showed varying percentages of smut in the crop.

The apparent ineffectiveness of seed disinfection was the principal factor which led to the recommendation of the open

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*Heald, F. D., and Woolman, H. M. Bunt or stinking smut of wheat. Bul. Wash. Agr. Exp. Sta. 126:1-24. 1915.

tank method of seed treatment, rather than to any actual demonstration of the part which the unbroken smut balls played in these results.

Spring plantings have shown little or no smut when the seed has been carefully treated, but fall plantings on summer fallow have very frequently shown high percentages of smut. The following records taken from information collected by Dr. H. B. Humphrey and H. M. Woolman, were typical of the farm conditions in the vicinity of Pullman:

TABLE I.

Percentages of Smut on Winter Wheat with Careful Seed Treatment (Blustone)

Tract	Year	On Sum. Fal.	Variety	Percentage of Smut
146	1912	1911	Forty Fold	10-18 North Slope
144	1912	1911	Red Russian	20-25 North Slope
142	1912	1911	Club ?	30
136	1912	1911	Hybrid 108	21-24 South Slope
133	1912	1911	Hybrid 128	15-20 North Slope
129	1914	1913	Red Russian	15-20
131	1914	1913	Hybrid 143	22 North Slope

POSITIVE EVIDENCE OF WIND DISSEMINATION OF STINKING SMUT

Foliage Collections. The discovery of the spores of bunt on the leaves of apple (already mentioned) led to a more systematic search for these spores on the foliage of various plants. During the fall of 1915, leaf collections were made from various localities from the following: prairie sunflowers (Balsamorhiza), apple, maple, catalpa, box elder, spiraea, and snowberry (Symphoricarpos). Each lot (usually 25 leaves) was put at once into a clean paper sack and brought to the laboratory. With a clean test tube brush the surfaces of each leaf were scrubbed in a small amount of distilled water in a damp chamber. The operation of scrubbing was carried out in the laboratory inoculation chamber, thus allowing no spores to enter from the outside. To the washings was then added a sufficient amount of formalin to prevent the germination of the spores, and the entire amount placed in clean flasks or

bottles properly labeled and numbered. Counts determining the approximate number of spores present, were made at a later date.

The quantitative determination of the number of bunt spores found present on each lot was determined by the following method. The flasks containing the washings were thoroughly shaken in order to get into suspension all the spores present. With a 1 c.c. pipette a drop was removed to a clean slide and covered with a 22mm. slip, the edges of which had been smeared with vaseline to prevent the evaporation of the water during the count. By use of the mechanical stage the diameter of the microscopic field was definitely determined. In counting, the slide was placed on the stage and, beginning at the upper right hand corner of the slip, the slide was moved across the field of view the exact width of the slip. The number of spores found present was then recorded and the slide moved up the diameter of the field, when another count was made. This was continued until the entire area of the slip had been gone over and all the spores present in the drop had been recorded. The sum was then multiplied by the number of drops found necessary to make a single cubic centimeter, the product being the total number of spores present in a cubic centimeter. Ten drops were counted from each collection, the number of spores per cubic centimeter determined, and the average number per cubic centimeter multiplied by the total number of cubic centimeters in the flask, gave the number of spores to each collection (approximately). The results obtained are presented in the appended table. (Table II.)

TABLE II.

Showing the Number of Smut Spores Obtained From the Foliage of Various Plants During the Early Part of September, 1915

Collection No.	Date of collection, Sept.	Location	Plant	No. of leaves	Total No. of spores	Ave. No. of spores per leaf
1	9	College Orchard	Apple	25	1,865,266	74,610
9	9	College Orchard	Apple	25	3,631,792	145,272
3	10	Round Top	Maple	28	249,612	8,914
4	10	Round Top	Catalpa	15	693,594	24,669
5	11	Timber Claim S.W.	Box Elder	25	616,519	24,660
6	11	Timber Claim E.	Box Elder	25	760,557	30,422
7	11	Timber Claim C.	Box Elder	25	609,193	24,367
8	18	Kamiak Butte	Spiraea	30	266,475	8,882
9	18	Kamiak Butte	Balsamorhiza	6	28,353	4,725
10	18	Kamiak Butte	Symphoricarpos	22	31,317	1,423

When making the foliage collections, plants were selected which were located some distance from any wheat field or threshing operation. The leaves were taken from the various parts of the tree or plant, and no especial attempt was made to secure leaves showing a dense collection of dust.

Collections No. 1 and 2 were taken from two different trees, both situated in the northeast corner of the old orchard on the College farm. Collection No. 1 was from a large well-matured tree, with rather small leaves. No. 2 was from an adjacent tree which was younger, growing quite vigorously, and the leaves were somewhat larger. Both trees were on a southeast slope and situated in such a manner as to be quite well protected from the full force of the prevailing westerly winds. It is probable that bunt spores and dust would tend to settle at this particular point, which probably accounts for the large number of spores found on these collections. The nearest wheat field was at least a half-mile distant, and the nearest threshing operation much farther.

Collections No. 3 and 4 were taken from several trees located on the highest point of the College farm. These trees are not protected in any manner and receive the full force of the wind. The nearest wheat field was several hundred yards to the north and it is extremely doubtful if any bunt spores from this field ever settled on the foliage of these trees. The nearest wheat fields, west of this point, were two and one-half or three miles distant.

Fig. 1. Contour map of Kamiak and vicinity, photographed from the Pullman Quadrangle map of the U. S. Geological Survey, showing where foliage collections were made.

Collections Nos. 5, 6, and 7 were taken from a timber claim north of the College farm. This claim was located at the top of a hill and was surrounded on the north, west, and south sides by summer-fallow, while the east side only adjoined a wheat field. As the prevailing winds are mostly from the westerly directions it would indicate that if bunt spores could be obtained from the foliage within this claim, the summer fallow adjoining must be "seeded" equally as heavily. The foliage collections taken from the southwest corner, the center,

and the east side of the claim gave evidence of enough spores present, to warrant this conclusion.

Collections Nos. 8, 9, and 10 were secured from the highest ridge of Kamiak Butte at a point at least 1000 feet above the surrounding farms and two or more miles distant from the nearest wheat fields.

Water Spore Traps. The fact that the foliage of plants harbored bunt spores in large numbers at once raised the question as to the probable number of spores falling on a square inch of surface throughout the season. In order to determine this the use of the water spore-traps at once suggested itself. A description of these traps and their method of use is given in detail by Heald* et al., in their work on the air and wind dissemination of ascospores of the chestnut blight fungus.

Traps for 1915. Beginning September 1st and extending over a period of six weeks, ending October 14th, two spore-traps were stationed on the college farm at points distant from any wheat fields. Trap No. 1 was located at least one-fourth mile from the nearest wheat field and about one and one-half miles from the nearest threshing operation. Trap No. 2 was located on a point just south of Round Top (previously referred to), was equally as far distant from any wheat field or threshing operation, and with regard to elevation, was at least 150 feet higher than Trap No. 1. Collections were made weekly and all ordinary precautions were used to prevent the entrance of spores from other sources. The method of determining the approximate number of spores present in each collection was the same as that described for the foliage collections. The results are presented in the appended table. (Table III.)

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*Heald, F. D., Gardner, M. W., and Studhalter, R. A. Air and wind dissemination of the ascospores of the chestnut-blight fungus. Journ. Agr. Res. 3:493-526. 1915.

TABLE III.

Record for Spore Traps During Season of 1915, Showing Wind Dissemination of the Spores of Bunt

Period Covered	Trap No. 1			Trap No. 2		
	Total No. of spores	No. of spores per sq. in.	No. of spores per sq. ft.	Total No. of spores	No. of spores per sq. in.	No. of spores per sq. ft.
Sept. 1-Sept. 8	155,175	3,978	572,832	119,262	3,058	440,352
Sept. 8-Sept. 16	58,806	1,507	217,008	63,591	1,630	234,720
Sept. 16-Sept. 23	21,720	557	80,208	25,977	666	95,904
Sept. 23-Sept. 30	17,028	436	62,784	12,995	333	47,952
Sept. 30-Oct. 7	4,926	126	18,144	2,475	63	9,072
Oct. 7-Oct. 14	12,078	309	44,496	8,712	223	32,112
*Total number of spores	269,733			233,012		
Total number per sq. in.		6,916			5,974	
Total number per sq. ft.			995,904			860,256

*The area of the traps was found to be 39 sq. in.

Traps for 1916. With the approach of the harvest of 1916, it was decided to place the water spore-traps out earlier in the season and if possible, run them later. On August 16, three traps were stationed on the College farm, and weekly collections made for a period of eleven weeks, ending November 1st, when the temperature conditions no longer warranted their continuance. Traps. Nos. 1 and 2 occupied the same positions as during the year 1915, while trap No. 3 was stationed on the College Pathologium in a rather sheltered position. Trap No. 1 was equally as far distant from any wheat field or threshing operation as during the season of 1915, while trap No. 2 was but a quarter of a mile north of a very smutty field of wheat. Trap No. 3 was located in a summer fallow field, which for a number of years had been an old raspberry patch. To the south of the trap, but a few yards distant, was located some of the experimental plots used in growing spring wheat. All traps were set when harvest was at its height and about two weeks before any threshing operations began in the immediate vicinity. However, threshing and combine harvesting were at their height in the central part of the state, north and west of the College farm. It was our object to ascertain, if possible, the probability of wind dissemination from points 50 to 75 miles distant, the period of maximum dissemination in the immediate vicinity and the probable duration of the period of dissemination. Our results are recorded in the appended table. (Table IV.)

TABLE IV.
Record for Spore Traps During the Season of 1916

Trap No. 1

Period Covered	No. of spores for the week	No. of spores per sq. in.	No. of spores per sq. ft.
Aug. 15-21	62,483	1,602	230,688
Aug. 22-28	143,866	3,688	531,072
Aug. 29-Sept. 4	200,000*	5,128	738,432
Sept. 5-11	420,732	10,788	1,553,472
Sept. 12-18	212,512	5,449	784,656
Sept. 19-25	52,896	1,356	195,264
Sept. 26-Oct. 2	40,194	1,030	148,320
Oct. 3-9	15,225	390	56,160
Oct. 10-16	12,931	330	47,520
Oct. 17-23	6,467	165	23,760
Oct. 24-30	11,866	304	43,776
Totals	1,179,172	30,235	4,353,840

*Estimated.

Trap No. 2

Period Covered	No. of spores for the week	No. of spores per sq. in.	No. of spores per sq. ft.
Aug. 15-21	43,343	1,111	159,984
Aug. 22-28	155,261	3,978	572,832
Aug. 29-Sept. 4	146,421	3,754	540,576
Sept. 5-11	520,142	13,362	1,924,128
Sept. 12-18	250,000*	6,410	923,040
Sept. 19-25	164,867	4,227	608,688
Sept. 26-Oct. 2	21,309	546	78,624
Oct. 3-9	19,348	496	71,424
Oct. 10-16	15,578	399	57,456
Oct. 17-23	6,467	165	23,760
Oct. 24-30	11,866	304	43,776
Totals	1,358,736	34,839	5,016,816

*Estimated.

Trap No. 3

Period Covered	No. of spores for the week	No. of spores per sq. in.	No. of spores per sq. ft.
Aug. 15-21	43,751	1,121	161,429
Aug. 22-28	200,108	5,130	738,720
Aug. 29-Sept. 4	319,725	8,198	1,180,512
Sept. 5-11	318,303	8,161	1,175,184
Sept. 12-18	188,602	4,835	696,240
Sept. 19-25	530,602	13,605	1,959,120
Sept. 26-Oct. 2	37,085	950	136,800
Oct. 3-9	21,344	547	78,768
Oct. 10-16	13,212	338	48,672
Oct. 17-23	5,379	137	19,728
Oct. 24-30	5,440	139	20,016
Totals	1,683,551	43,161	6,216,048

Average No. of spores per trap for the season.....1,407,153
Average No. of spores per sq. in. for the season..... 36,113
Average No. of spores per sq. ft. for the season.....5,162,234

An examination of the records from the spore-trap collections shows for the season of 1915 that the maximum spore-fall occurred previous to or during the first week of September, since there was a gradual decline in the number of spores falling on each square foot of surface following the first week of record.

For the season of 1916 there is a general agreement in the results from the traps located at the three different stations. During the first three weeks from Aug. 15 to Sept. 4 there was a gradual increase in the spore-fall, the maximum fall occurring in each case during the week of September 5-11. It is worthy of note that this week was also one of high wind velocity (see Fig. 2). Following the maximum there was a gradual decline in the spore fall through the last weeks of September; during the month of October, spores were still present, but in greatly reduced numbers. It has been shown in our experimental plantings that the highest per cent of smut infection occurred during the month following the maximum spore fall.* During this period there was plenty of moisture, the temperature conditions were favorable for smut, and the abundance of smut spores in the soil, gave as high as 41 per cent of smut from clean treated seed. These results point to the conclusion that wheat seeded in summer fallow during the period following the maximum spore-fall (last of September and first of October) is likely to be heavily smutted.

RELATION OF CLIMATIC CONDITION TO THE SMUT SHOWERS

Wind Intensity and Velocity. The climatic conditions of the Palouse country, previous to, including, and a few weeks following the threshing season are especially favorable for the wide-spread dissemination of the spores of stinking smut. The period is invariably characterized by bright sunshine, a very slight or often no rainfall, and a rather high wind velocity, especially at certain periods. The typical Palouse dust storm

*Heald, F. D. The stinking smut of wheat. Pop. Bul., Wash. Exp. Sta. 115:10-11. 1918.

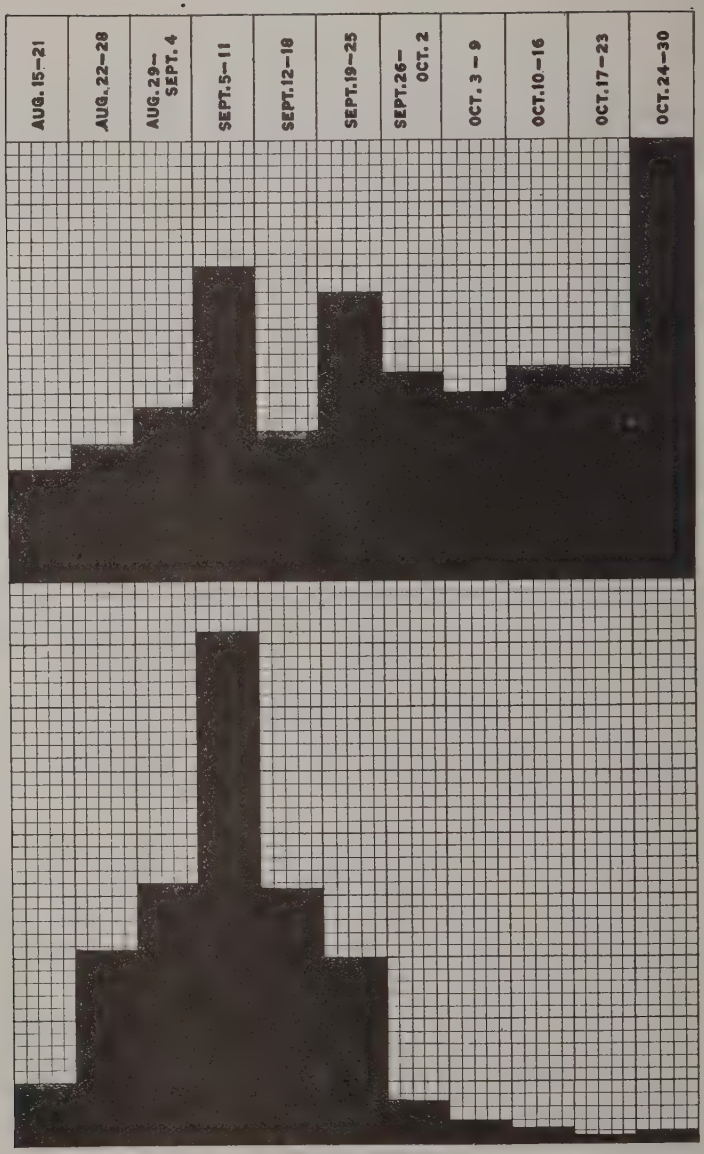

Fig. 2. Diagrams showing the spore fall and wind velocity from August 15 to October 30, 1916. The lower figure represents the spore fall, based on the total number of spores collected, and each square represents 2000 spores; the upper figure shows the wind velocity based on the average number of miles per day for 24 hours, for the week covered. Each square represents two miles. Diagram by D. C. George, formerly Assistant Pathologist.

is the culmination of a period of high wind velocity. This combination of factors makes the wheat straw very dry and brittle as well as causing a pronounced desiccation of the smut balls. The operators of threshing outfits take advantage of these dry conditions and run the separators at a very high rate of speed. This naturally causes the complete breaking up and crushing of the greater number of the smut balls, and as all machines are equipped with wind or fan stackers, great numbers of smut spores are thus shot into the air, and must ultimately find a resting place on either adjacent or distant fields.

Taking these facts into consideration it is interesting to note the relation of the wind velocity to the fall of the smut spores. The Division of Soils of the Experiment Station very kindly furnished us the wind records, covering the period during which the spore traps were set for the season of 1916. The results are graphically represented in the accompanying illustration. (Fig. 2.)

Rainfall. As previously mentioned there is a very small amount of rain during the harvesting and threshing season. The accompanying table (Table V) gives the rainfall for Pullman from June to October during the last three seasons.

TABLE V.

Rainfall in Inches at Pullman, June to October, 1915-1917

Month	1915	1916	1917
June	0.53	2.34	0.56
July	0.77	0.45	0.00
August	0.00	1.24	0.00
September	0.63	0.68	0.84
October	1.23	0.35	0.00

It may be noted that the season of 1917 was exceptionally dry, with a total of only .84 inch of rain during the four months covering harvesting and threshing operations in Eastern Washington and adjacent territory. Even during 1916, when the rain-fall was above normal for the period, the conditions were still very favorable for the wind dissemination of smut. We must conclude then that the average weather conditions which prevail in the wheat belt of Eastern Washington are conducive

to a wide-spread wind dissemination of the spores of bunt. Combine with this wide-spread scattering of smut a farming system which includes summer fallow and fall seeding and we have the explanation for the smut menace of Eastern Washington.

SUMMARY

Seed treatment, the effective practice for the control of bunt or stinking smut of wheat in other wheat-growing sections, has not been effective for winter wheat in the Palouse country.

Bunt is one of the cereal smuts in which the infection takes place only through young seedlings, either from seed-borne spores or from spores already in the soil.

The possibility of a wind-dissemination of the spores of bunt has been recognized. It has been shown that wind-borne secondary spores or sporidia play no part in the spread of smut, since there is no spread of smut from an infected to an uninfected field during a single season. Scattering of spores from smutted heads previous to harvest is of minor consequence, but during the threshing operations the smut balls are broken up and much of the smut dust is carried out through the stacker. Much of this smut dust must ultimately come to rest on the surrounding fields.

The wide-spread wind-dissemination of the spores of bunt was suggested by the visible clouds of smut dust which issue from threshing machines whenever the run is in a smutty field; the presence of smut spores on vegetation distant from any threshing operations; the production of smutty wheat when clean treated seed was sown on land, which had not previously produced a crop of smutty wheat; and also by the general ineffectiveness of seed treatment for fall-sown wheat.

Positive evidence of this widespread dissemination of the spores of bunt has been obtained by the microscopic analyses of the washings of foliage taken from stations distant from any threshing operations. This was further substantiated by the use of water spore-traps, which have made possible the de-

termination of the actual number of spores falling on a given area.

During the threshing season there is a "smut shower" or spore-fall in the vicinity of Pullman, which begins in August, increases to a maximum and gradually subsides. During the season of 1916 the maximum fall occurred from the 5th to the 11th of September. The exact time of the maximum will depend in part on the location, the period when threshing operations are the most numerous, and also upon climatic factors.

The dry conditions which prevail during the threshing period, together with frequent winds of high velocity, and a farming system which includes summer fallow and winter wheat, have combined to make wheat smut especially severe in the Palouse country.

The greater amount of winter wheat is seeded in summer fallow which has received countless numbers of wind-blown spores; the maximum amount of seeding generally follows the period of maximum spore-fall, and at this time both temperature and moisture conditions are especially favorable for smut.